On the forward - backward effect in the *(n,p)* reaction on ^{35}Cl and ^{14}N

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Abstract. In the present paper we use the mixing states of the compound nucleus model in the two resonances approximation with the same spins and opposite parity [1] for the evaluation of the asymmetry effects in the cases of *(n,p)* reaction on ^{35}Cl [2] and ^{14}N nuclei. We make a theoretical evaluations of the total cross sections, differential cross sections and of the asymmetry coefficients forward-backward (FB), left-right (LR) and parity non conservation (PNC) and fitted the theoretical results of the FB coefficient with the experimental measured values, for obtaining the relative partial widths for proton in the outgoing channel and neutron in the entrance channel. The experimental measurements were held at Frank Laboratory of Neutron Physics, JINR, for ^{35}Cl at the IBR-30 reactor and for ^{14}N at Electrostatic Generator EG-5, in the both cases was used the double ionization chamber.

INTRODUCTION.

For the evaluation of the asymmetry effects in the *(n,p)* reactions on the mentioned nuclei for the neutrons incident energies we used the model of the mixing states of the compound nucleus with the same spin and opposites parities [3, 4]. In the frame of this formalism it is shown that the asymmetry effects are results of the presence of two resonances with the same spin and opposite parities. For the $^{35}Cl(n,p)^{35}S$ the energy of incident neutrons is not greater than *1 keV* and for the $^{14}N(n,p)^{14}C$ reaction the incident energy is around *500 keV*. In the mentioned incident neutrons energy it is possible to apply the so called “two levels approximation” because in these energy ranges the main contribution in the cross sections and asymmetry effects is given by two states of the compound nucleus (or two resonances). The theoretical and experimental evaluation gives us in principal new information about nuclear structure and mechanism reaction but one of the main idea of these evaluations is to obtain from them the weak matrix element as was suggested in [5]. The approach described in [5] for the first time have been realized in the case of $^{35}Cl(n,p)^{35}S$ [6] reaction where the weak matrix element was extracted from the FB, LR and PNC experimental coefficients in this way being eliminated the problem of the sign of the asymmetry effects, partial and reduced widths and different phases.

In this paper we just present the theoretical evaluation of the asymmetry effects for both reactions and using some unpublished experimental data on FB effects we try to obtain some values for the reduced neutron and proton widths by fitting these data.

BASICS OF THEORETICAL FORMALISM.

In the ’80 years of the last century it was developed a theoretical formalism for the explanation of the asymmetry effects involving *P* and *T* violation phenomena in the *(n,γ)* and fission reactions named the formalism of the mixing states of the compound nucleus with the same spin and opposite parities [3, 4]. This formalism was able to explain the parity violation effects in the mentioned reactions first time evidenced experimentally by Abov and collaborators [7] and later from other experiments.

This formalism assumes that the nuclear reaction is going by formation of the compound nucleus and the asymmetry and parity violation effects can be observed when the compound nucleus will be described at least by two states (resonances) having the same spin and opposite parities. As these states are closer one to another as the effects have a higher value or we can say they are amplified. The amplification mechanisms are very well described in [4, 8].

The formalism of the mixing states of the compound nucleus with the same spin and opposite parities supposes that for each kind of compound nucleus state it is possible to write a Breit – Wigner resonance type semi empirical amplitude [3, 4] based on existing determined experimental widths [9, 10].

Experimental data on $^{35}Cl(n,\gamma)$ reaction induced by polarized thermal neutrons showed some asymmetry effects in the integral gamma spectrum measurements explained by the presence of the weak interaction [11]. The weak matrix element extracted from this reaction was about one order of magnitude higher than the value suggested in [12]. Another way to obtain the weak matrix element was the $^{35}Cl(n,p)^{35}S$ reaction with thermal and resonance neutrons. For incident thermal neutrons the states of the compound nucleus contributing to the asymmetry effects for ^{35}Cl are the S state with $E_S = -180\ eV$, $J^{\Pi} = J_S = 2^+$ and respectively the P state with $E_P = 398\ eV$, $J^{\Pi} = J_P = 2^-$.

For obtaining the mentioned effects the (n,γ) amplitudes from the formalism of the mixing states of the compound nucleus with the same spin and opposite parities easy can be adapted for (n,p) reaction. We do not write them we just mention that they can be found in [1] and other works of this Seminar from previous years [13, 14].

For the $^{14}N(n,p)^{14}C$ reaction the levels of the ^{15}N compound taken into consideration for the evaluation of the asymmetry effects, the same as in the $^{35}Cl(n,p)^{35}S$ reaction (the FB, LR and PNC coefficients) are the P state with $E_P = 492.6\ keV$ and $J^{\Pi} = J_P = (1/2)^-$ respectively the S state $E_S = 639\ keV$ and $J^{\Pi} = J_S = (1/2)^+$.

RESULTS.

The FB, LR, PNC asymmetry effects in the frame of the mixing states of the compound nucleus with the same spin and opposite parities using the two level approximation in the case of $^{35}Cl(n,p)^{35}S$ reaction are [2]:

$$\alpha_{FB} = (X_n - Y_n)(X_p - Y_p) f_{FB}(E) \tag{1}$$

$$\alpha_{LR} = (X_n + \frac{Y_n}{2})(X_p - Y_p) f_{LR}(E) \tag{2}$$

$$\alpha_{PNC} = W_{SP}(X_p - Y_p) f_{PNC}(E) \tag{3}$$

For the $^{14}N(n,p)^{14}C$ reaction using the same formalism and the same approximation we obtain analogous relation for the FB, LR and PNC coefficients. The expressions of the evaluated theoretical effects are:

$$\alpha_{FB} = -\left(X_n + 2\sqrt{2}Y_n\right)X_p f_{FB}(E_n) \quad (4)$$

$$\alpha_{LR} = \left(-X_n + 2\sqrt{2}Y_n\right)X_P f_{LR}(E_n) \quad (5)$$

$$\alpha_{PNC} = W_{SP} X_p \left(\frac{1}{2} c_1(E_n) \sqrt{\frac{\Gamma^n_{S_1}}{\Gamma^n_P}} + c_2(E_n) Y_n^2 \sqrt{\frac{\Gamma^n_P}{\Gamma^n_{S1}}} \right) f_{PNC}(E_n) \quad (6)$$

The terms included in relations (1-6) are:

- (X_n, Y_n, X_p, Y_p) the partial reduced amplitudes for neutrons and protons defined in [1,2,6]
- W_{SP} = the weak matrix element.
- The *f()* and *c()* terms are functions depending on the incident neutron energy

The partial reduced amplitudes have the properties (unknown parameters):

$$X_n^2 + Y_n^2 = 1,\ X_p^2 + Y_p^2 = 1,\ -1 \le X_{n,p}, Y_{n,p} \le 1 \quad (7)$$

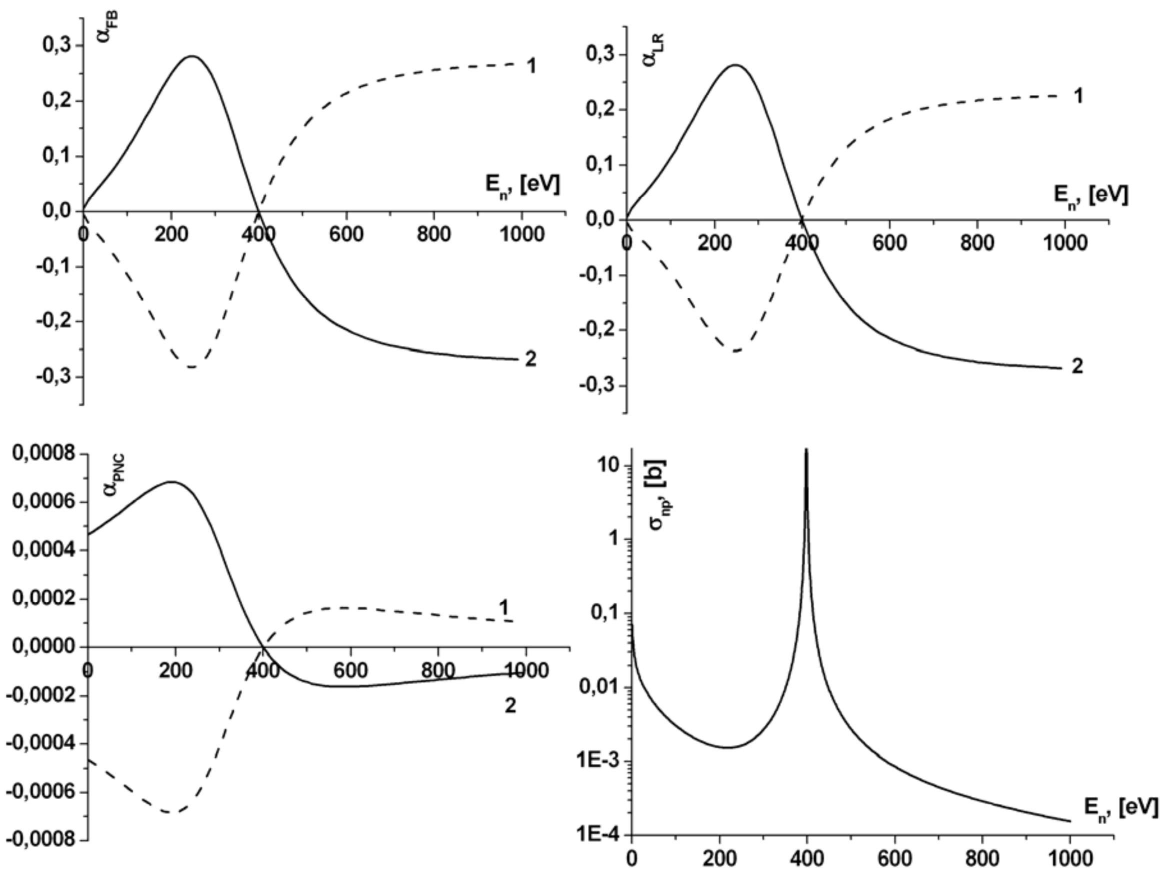

Fig 1. The theoretical energy dependence of the asymmetry coefficients, FB, LR, PNC and of the cross section, in the two levels approximation in the $^{35}Cl(n,p)^{35}S$.

1 – (*Xn = Xp=-Yn=-Yp=0.707*); 2 – (*Xn = Xp=-Yn=-Yp=-0.707*); W_{SP} = *0.06* eV.

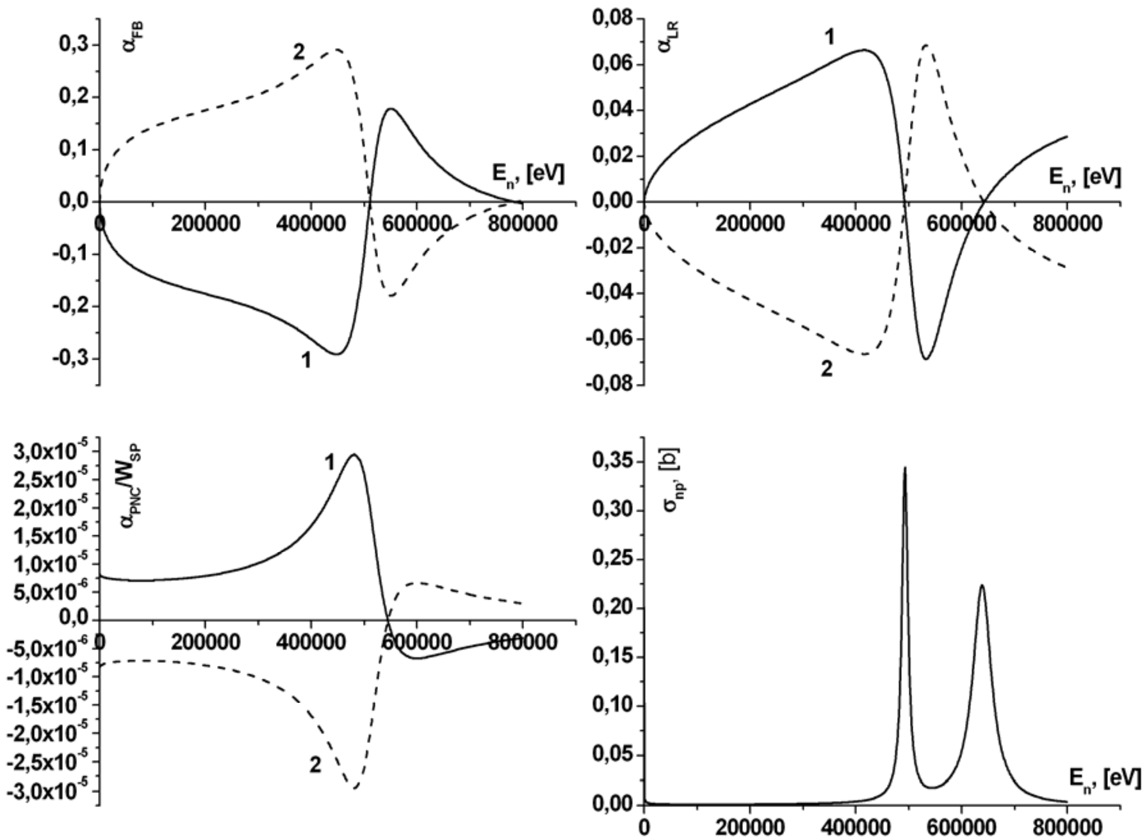

Fig. 2. The theoretical energy dependence of the asymmetry coefficients, FB, LR, PNC and of the cross section, in the two levels approximation for the $^{14}N(n,p)^{14}C$ reaction.
1 – (*Xn = Xp=Yn=0.707*); 2 – (*Xn = Xp=-Yn=-0.707*). The weak matrix element is unknown and we divided the PNC effect to the weak matrix element.

The relations (1-6) suggest that if we have experimental data for FB, LR and PNC we can in principle to extract the weak matrix element as already was done in [2, 6]. The obtained weak matrix element in these papers is $W_{SP} = (0.057 \pm 0.0012)\, eV$.

In the beginning of 2000's year the FB coefficient was measured at the IBR30 reactor using a double gridded ionization chamber in the $^{35}Cl(n,p)^{35}S$ reaction for incident neutrons energy up to *1 keV* . Some of these experimental data was preliminary published in [14] where the experimental FB effect was $\alpha_{FB} = (23 \pm 2.3) \cdot 10^{-2}$ for neutrons incident energy approximately about *260 eV* [2, 6, 14]. For the LR and PNC effects in the thermal point (E_n = *0.0253 eV*) the experimental values are: $\alpha_{LR} = -(2.4 \pm 0.43) \cdot 10^{-4}$ and respectively $\alpha_{PNC} = -(1.51 \pm 0.34) \cdot 10^{-4}$ [15].

In the Fig. 3 were represented the theoretical and experimental dependences of the FB effect in the $^{35}Cl(n,p)^{35}S$ with incident neutrons up to *1 keV*. Using experimental values with their errors for the FB effect, it was extracted the following value for the term containing partial reduced amplitudes: $(X_n - Y_n) \cdot (X_p - Y_p) = -(0.916 \pm 0.34)$.

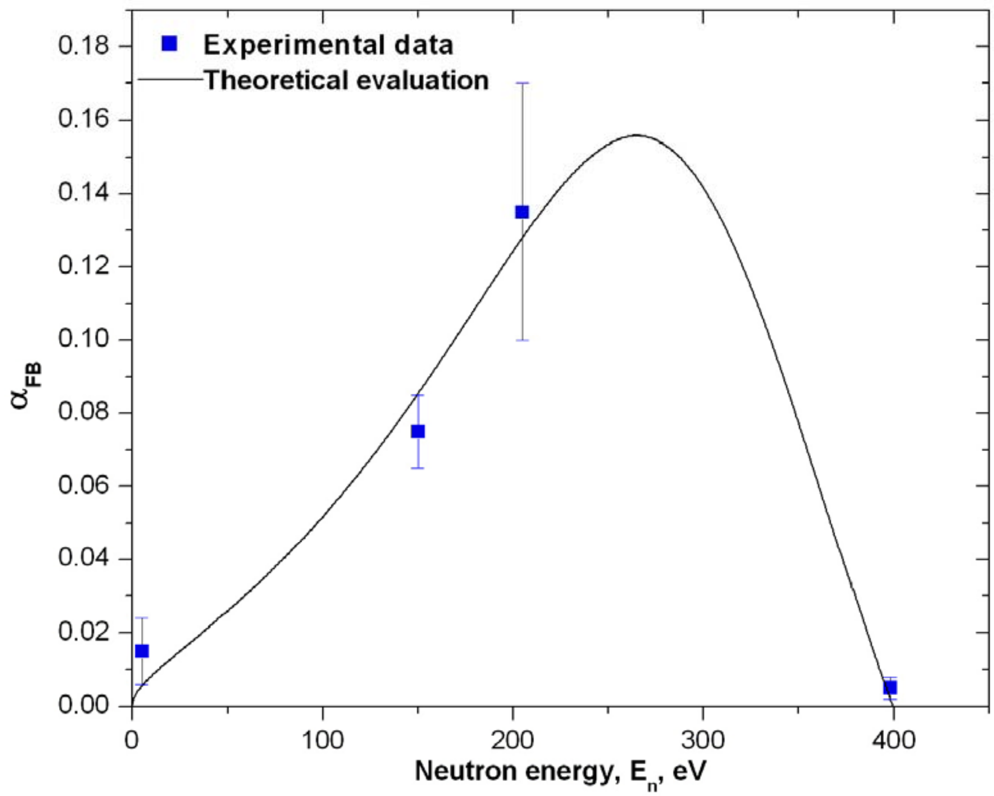

Fig. 3. Experimental and theoretical FB effects for $^{35}Cl(n,p)^{35}S$ reaction.

DISCUSSIONS.

The experimental data in the mentioned reaction and asymmetry effects are very poor because the cross section is very small where the effects have high values and big where the effects are small. For the analyzed energy dependence the *(n,p)* reaction is affected by a serious background due to the *(n,γ)* reaction. In the $^{14}N(n,p)^{14}C$ reaction the experimental data for the asymmetry effects are also practically one for each effect. These values are: $\alpha_{LR} = (0.66 \pm 0.18) \cdot 10^{-4}$, $\alpha_{PNC} = (0.07 \pm 0.12) \cdot 10^{-4}$ for thermal point [15] and a preliminary data for FB effect is $\alpha_{FB} = (4.2 \pm 4.0) \cdot 10^{-2}$ for neutron energy mediated from *1 keV* up to *1 MeV* [16].

For the $^{35}Cl(n,p)^{35}S$ reaction the two level approximation is working very well up to *1 keV* neutrons incident energy and this is demonstrated first by the good agreement between the experimental (http://www-iaea.nds.org) and our theoretical cross section. The experimental LR and PNC asymmetry effects in the thermal point and the FB effect for *260 eV* neutrons energy are in a good agreement with our theoretical estimations.

For the $^{14}N(n,p)^{14}C$ reaction the situation are a little bit complicated. In the thermal point the theoretical cross section is lower than the experimental cross section. Also differences are in other energy range and this suggests that it is necessary to include the contribution of other resonances. But for a qualitative analysis the agreement between theoretical and experimental effects is satisfactorily. The experimental PNC effect is practically zero and this value is confirmed by theoretical estimation. This is a results of a few factors: the ^{14}N nucleus is a light one and the resonances of the compound nucleus, ^{15}N, are more far away one from each other and they are not so sharp resulting a small amplification due to described mechanisms [4,8].

In the future it is necessary to have a more complete experimental energy dependence of the asymmetry effects for both reactions in order to have the possibility to obtain the appropriate values for partially reduced amplitude for neutrons and protons and in the next step to obtain the weak matrix element. If for the $^{14}N(n,p)^{14}C$ reaction we have already clarified that is necessary to analyze the influence of other resonances at least up to *1 MeV* for the $^{35}Cl(n,p)^{35}S$ reaction is necessary to do the same if the incident neutrons energy will be higher than *1 keV* where in principle the two level approximation it is expected to not work.

The work was partially realized by the financial support of the Romanian Plenipotentiary Representative to JINR Dubna in 2009.

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